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Plasma diagnostics during magnetron sputtering of aluminum doped zinc oxide

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Plasma parameters during magnetron sputtering of aluminum-doped zinc oxide are investigated with optical emission spectroscopy, electrostatic probes and mass spectrometry with the aim of understanding the role of negative ions of oxygen during the film growth and improving the uniformity of the film resistivity over the deposition area.

Transparent conductive interconnects are widely used for solar cells, touch panels, large area displays, lightening and smart windows. So far tin doped indium oxide is successfully used but the limited abundance of indium requires alternative materials. Zinc is 1000 times more abundant than indium and aluminum is the most abundant metal. On top of this, zinc oxide is easy to produce and exhibits very interesting properties (high electron mobility, a wide bandgap of 3.37 eV, good transmittance in UV and visible range, strong luminescence at room temperature, etc.) that have been used for various applications (i.e. ceramic materials, medicine, optoelectronic applications) [1]. ZnO is a transparent n-type semiconductor with a very high resistivity when deposited as thin film, therefore doping is necessary to make it conductive. Al, Ga, B, Cd and other elements have been considered as dopants and several methods have been developed to deposit thin films with resistivity in the order of 10^{-3} Ωcm or below. Due to its scalability to large area processing, magnetron sputtering is one of the most promising methods to deposit aluminum-doped zinc oxide (AZO) [2]. However, producing uniform films with resistivity in the range of 10^{-4} Ωcm and mobility above 20 cm^2/Vs is still an open problem. Up to date two mechanisms are targeted as responsible, including bombardment with energetic negative ions of oxygen and nonuniform distribution of oxygen concentration during the deposition process [3].

The aim of this work is to investigate the plasma parameters during magnetron sputtering of AZO and correlated it with the film properties (resistivity, mobility, carrier concentration).

The AZO films were deposited in a large sputtering chamber that can accommodate 8 samples (1×6 cm) on a rotating stage. The sputtering cathode was operated in RF (13.56 MHz) using a 2 inch target (Kurt Lesker) of ZnO doped with 2% of aluminum. The base pressure was below 10^{-6} Torr, the target was pre-sputtered for 30 min and then, the samples were positioned, one by one, under the cathode by changing the discharge pressure (Ar gas) and target to substrate distance for a deposition time of one hour. There was no additional heating except for that resulted from plasma. An optical fiber was inserted in a metallic tube (6 mm in diameter) terminated with a small quartz window and an additional ceramic tube of 1 mm in external diameter and 1 cm long used to prevent deposition on the quartz window and to collimate the light. A Langmuir probe was translated using a moving stage under the cathode at certain distances to record the radial profile of the ion saturation current. An additional vacuum chamber equipped with a mass spectrometer was used to detect the O^-. The sheet resistance, the optical transmittance and the film thickness were measured with a spatial resolution of 1 mm along the 6 cm long sample. Smaller samples of 3×3 mm were cut along from the large sample to measure the XRD and SEM patterns, the carrier concentration and the charge mobility.

The sheet resistance for different discharge pressures for a target to substrate distance of 2 cm and 20 W discharge power is presented in Fig. 1 (a), where from a similar correlation of the film properties with the erosion track on the target surface, as previously reported, can be identified. Detailed spatial measurements of negative ion distribution have related this behavior with the energetic negative ions of oxygen of high current density at the erosion tracks [3]. The thickness of the films from Fig. 1 (a) is presented in Fig. 2 (a) while the resistivity and Hall mobility for 1.4 and 3 mTorr are presented in Fig. 2 (a) and (b), respectively. Magnetron sputtering at 1.4 mTorr is very close to the discharge ignition

limit and exhibits a collimated discharge of low plasma density that led to a low thickness deposition and a sheet resistance above 100 Ω/sq at the sample center. The very low thickness (below 50 nm) at 1.4 mTorr and r=0 can be associated with a competition between deposition and re-sputtering by energetic species and low plasma density. The pressure increase to 3 mTorr resulted in two maxima for the sheet resistance, correlated with the erosion tracks, and that were getting closer to each other by increasing the pressure. The film thickness at 3 mTorr was 10 times larger (500 nm) for r=0 than at 1.4 mTorr, clearly showing that the discharge was now operating in an effective magnetron sputtering regime. Further increase in the discharge pressure has led to higher sheet resistance values at the center and values of less than 10 Ω/sq near the sample edge ($|r|$>20 mm) where the lowest resistivity and the highest mobility was obtained for 3 mTorr.

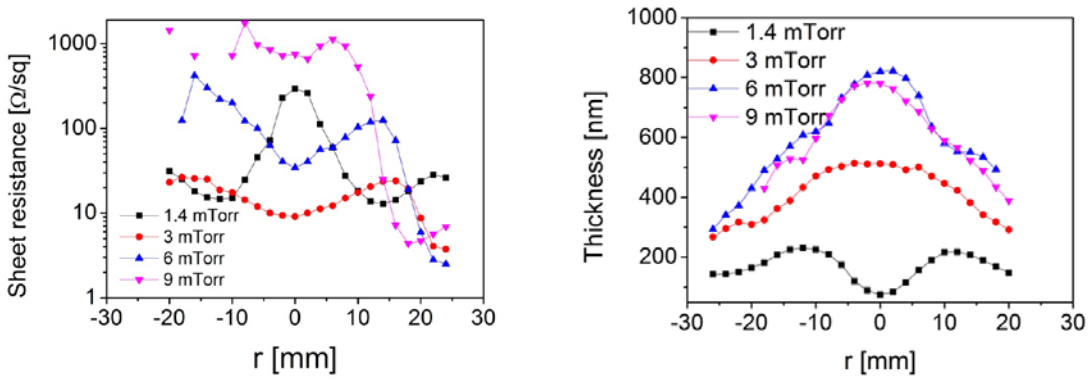

Fig. 1 (a) Sheet resistance and (b) film thickness for 20 W RF power and 2 cm target to substrate distance.

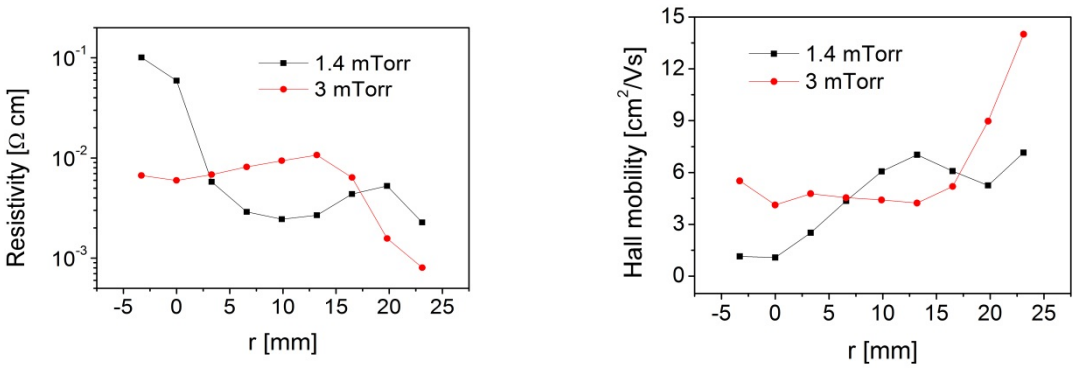

Fig. 2 (a) Resistivity and (b) Hall mobility for 20 W RF power and 2 cm target to substrate distance.

The Hall mobility was above 14 cm^2/Vs also at the edge of the sample for 3mTorr. The transmittance was more than 80% for all samples presented in this work. The correlation between plasma parameters and film properties will be presented during the conference.

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